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# Recurrent CME-like Eruptions in Flux Emergence Simulations

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IRIS 9 – June 25-29, 2018

**IRIS-9, Göttingen, 25-29 June 2018**

Contributed Talk

4. Eruptions in the solar atmosphere

# Recurrent CME-like Eruptions in Flux Emergence Simulations

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We report on three-dimensional MHD simulations of recurrent small-scale Coronal Mass Ejection (CME)-like eruptions using flux-emergence simulations and study their formation and eruption mechanism. These eruptions have the size and energies of small prominence eruptions. The erupting flux ropes are formed due to the reconnection of J-loops (formed by shearing and rotation) and are located inside magnetic envelope field favouring torus instability. The flux rope eruptions are triggered by the action of a tension removal mechanism, such as the typical tether-cutting where the envelope field reconnects with itself. Another side tether-cutting is also found. There, the envelope field reconnected with the J-loops. The two tether-cutting mechanisms transfer hot plasma differently inside the erupting structures. We report similar mechanisms creating three more eruptions in a recurrent manner.

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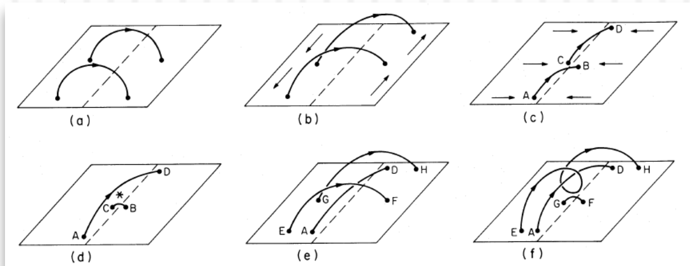
# Introduction - Recurrent Eruptions

It is common for a single AR to produce several eruptions (e.g. Nitta+ 2001, Wang+ 2013)

buoyant magnetic flux

Flux emergence



Van Ballegooijen and Martens 1989

Reconfiguration of environment

Flux rope formation

Relaxation of fields

Eruption

<u>Resistive mechanisms ?</u>

A. Tether cutting
B. Reconnection with external field

<u>MHD Instabilities/LE ?</u>

A. Torus Instability
B. Kink Instability

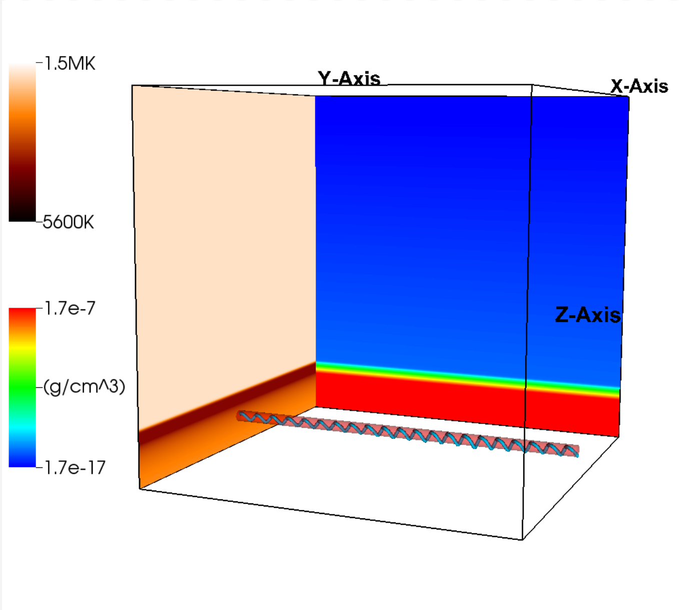
# Initial Conditions

- Flux tube oriented along the y-axis

$$B_y = B_0 e^{-\frac{r^2}{R^2}},\ R = 450km$$
$$B_\phi = \alpha r B_y$$
$$\Delta\rho = \frac{p_t(r)}{p_{st}(z)} \rho_{st}(z) e^{-\frac{y^2}{\lambda^2}},\ \lambda = 5$$
$$B_0 = 3150G$$

High twist: $\alpha$=0.4 45$^o$ $B_\phi$, $B_y$

- Positioned at 2.1Mm below photosphere
- $B_0$=3150 G



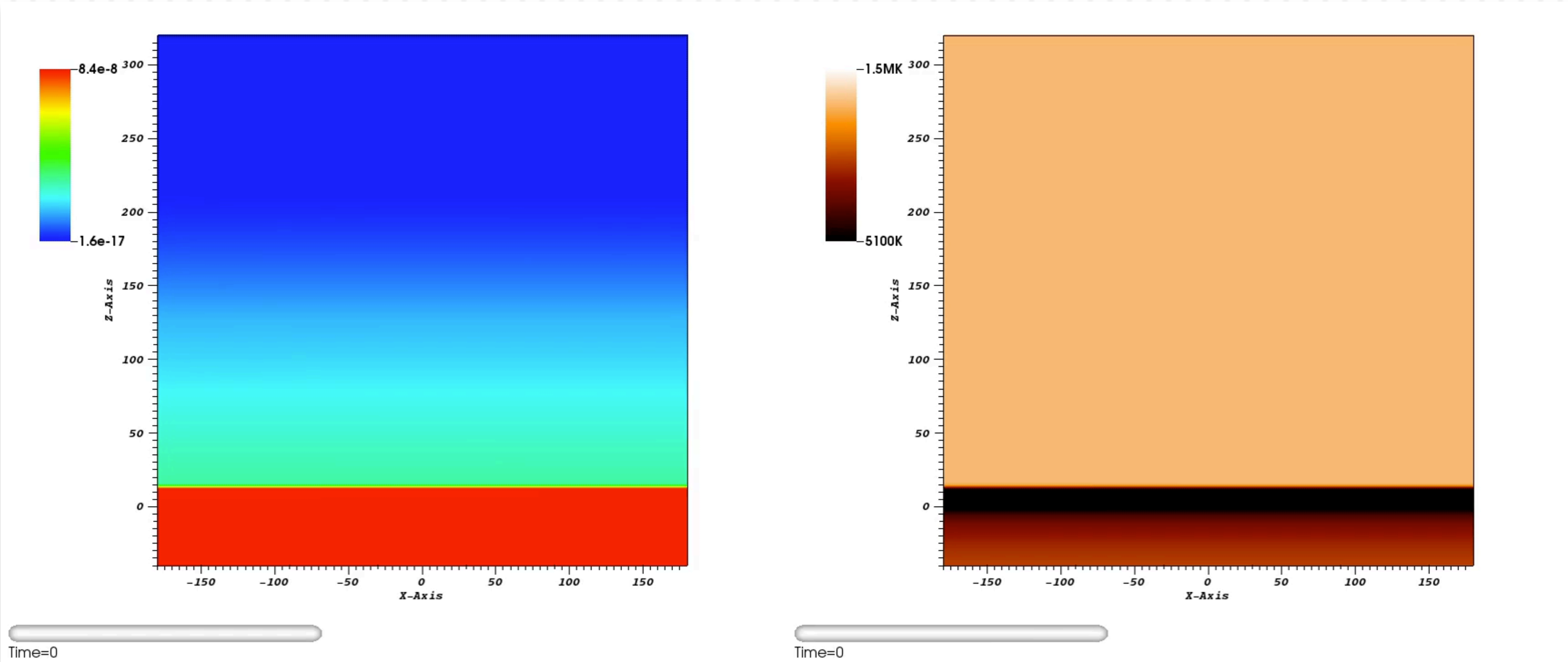

Numerical domain of 64.8$^3$ Mm

- Photosphere-chromosphere: 1.8 Mm
- TR: 1.8-3.2 Mm
- Corona: 3.2-56.7 Mm

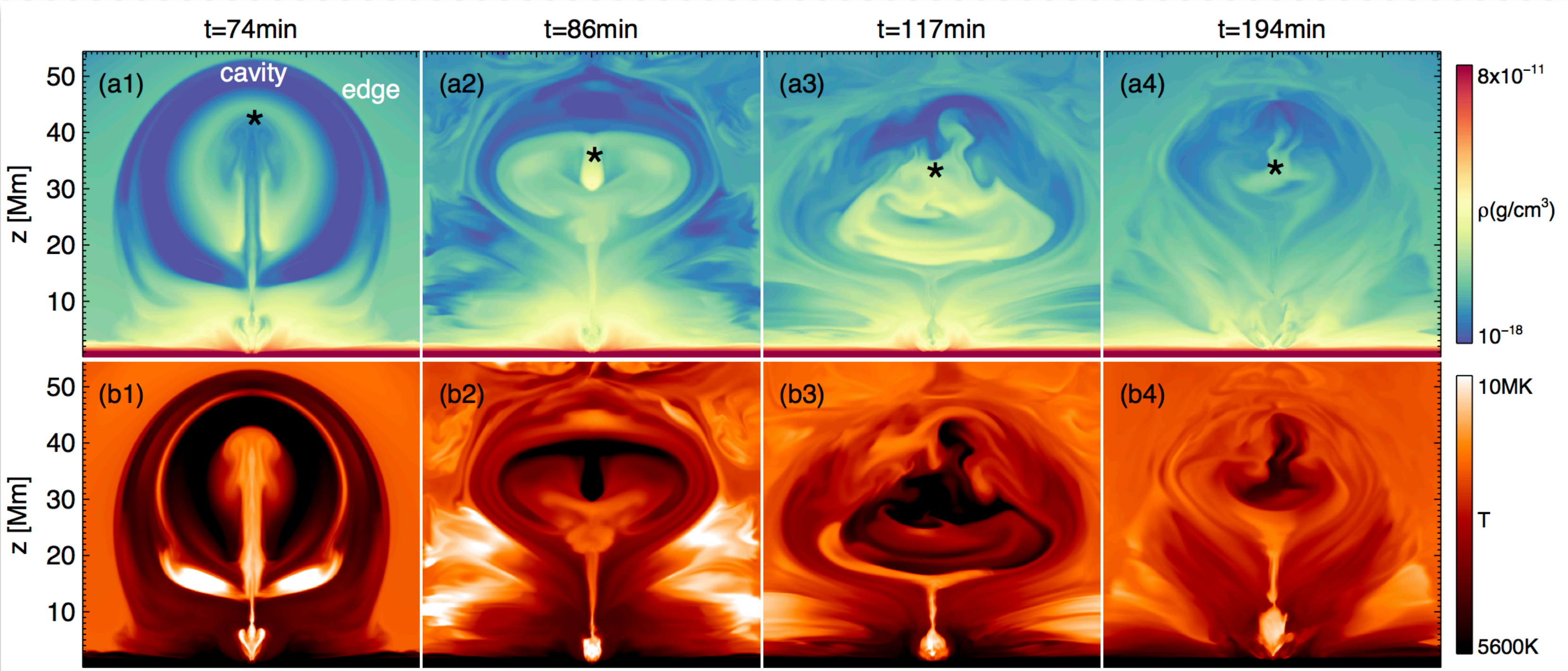
$$\frac{\partial\rho}{\partial t} + \nabla\cdot(\rho\mathbf{v}) = 0,$$
$$\frac{\partial(\rho\mathbf{v})}{\partial t} = -\nabla\cdot(\rho\mathbf{v}\mathbf{v}) + (\nabla\times\mathbf{B})\times\mathbf{B} - \nabla P + \rho\mathbf{g} + \nabla\cdot\mathbf{S},$$
$$\frac{\partial(\rho\epsilon)}{\partial t} = -\nabla\cdot(\rho\epsilon\mathbf{v}) - P\nabla\cdot\mathbf{v} + Q_{joule} + Q_{visc},$$
$$\frac{\partial\mathbf{B}}{\partial t} = \nabla\times(\mathbf{v}\times\mathbf{B}) + \eta\nabla^2\mathbf{B},$$
$$\epsilon = \frac{P}{(\gamma-1)\rho}$$

**Non magnetized** stratified atmosphere
Anomalous resistivity
**No** heat conduction/radiative losses

# Eruptions – Overview



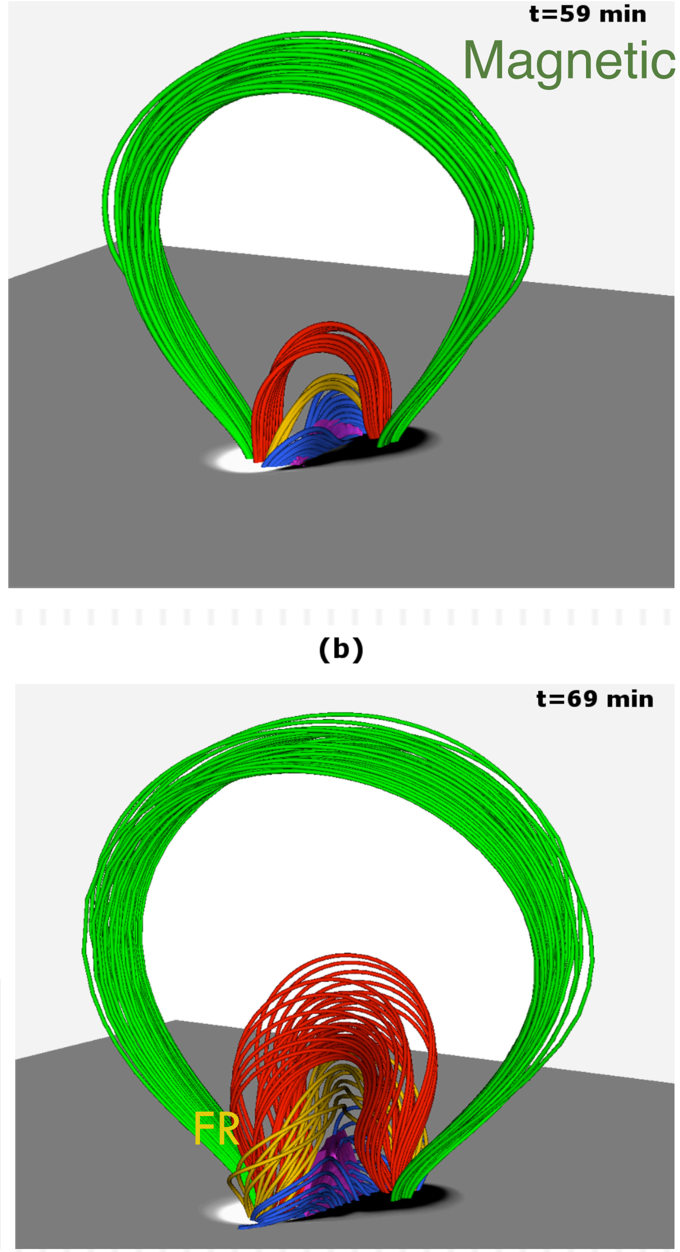
# Eruptions – Overview

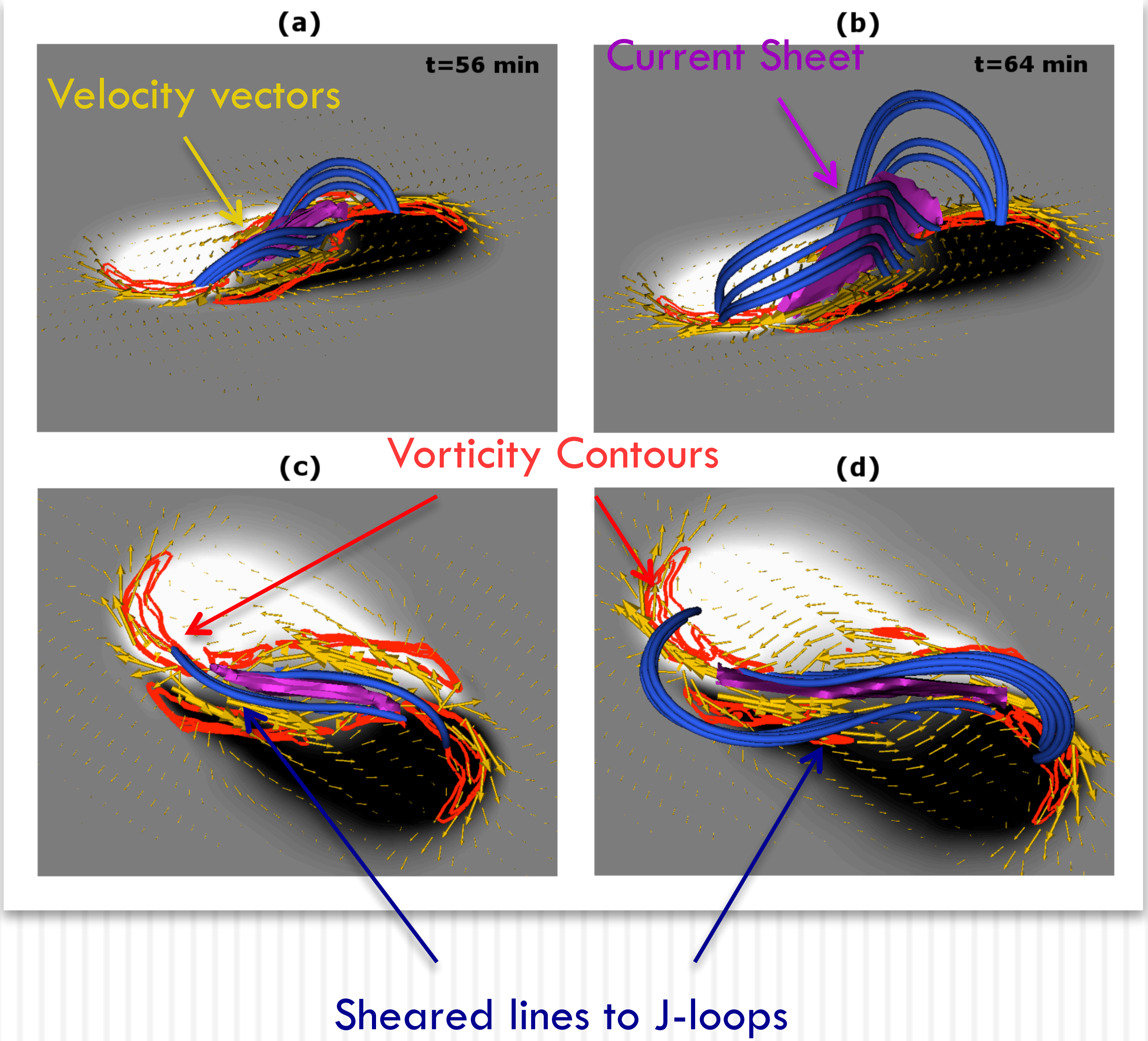



Observations suggest that not all CMEs have a hot core (e.g. Nindos+15)

We will focus on the reason of why we do not find a hot core in our simulation.

# 1st Eruption – Mechanism I



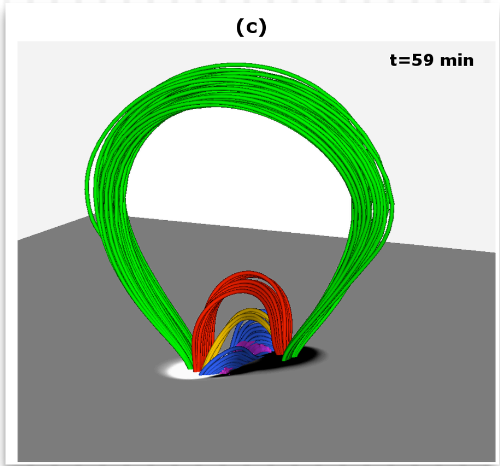



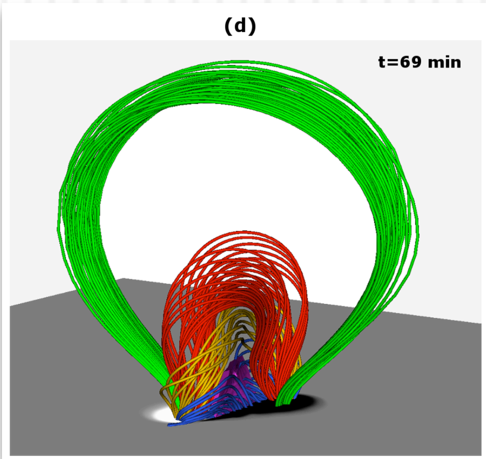
# 1st Eruption – Mechanism

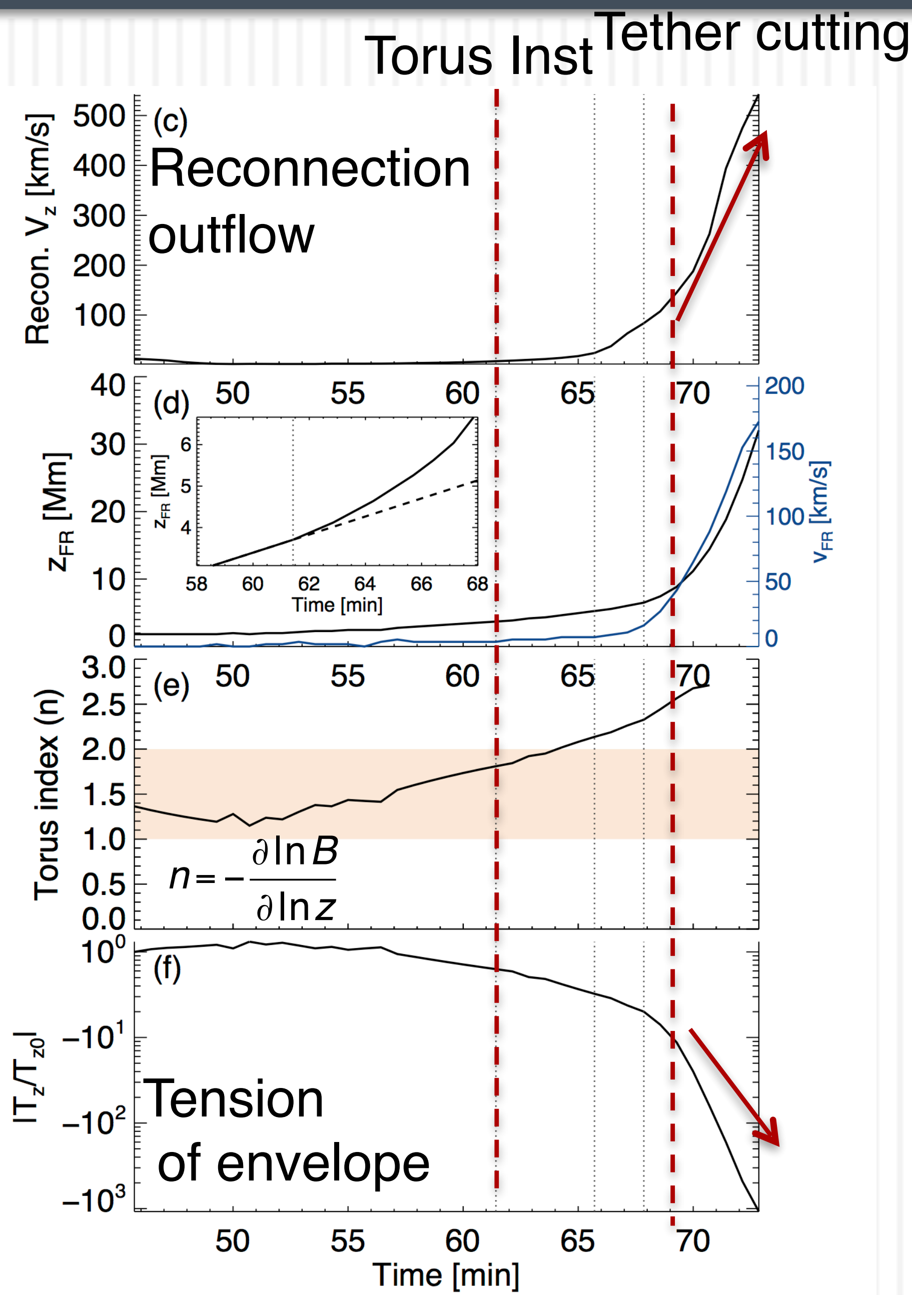
1. Find the h-t profile
2. Find Torus index at the flux rope position

- Flux rope is in the Torus region (n=[1-2]) from the early stages
- Eruptive phase starts after the tether-cutting of the envelope field

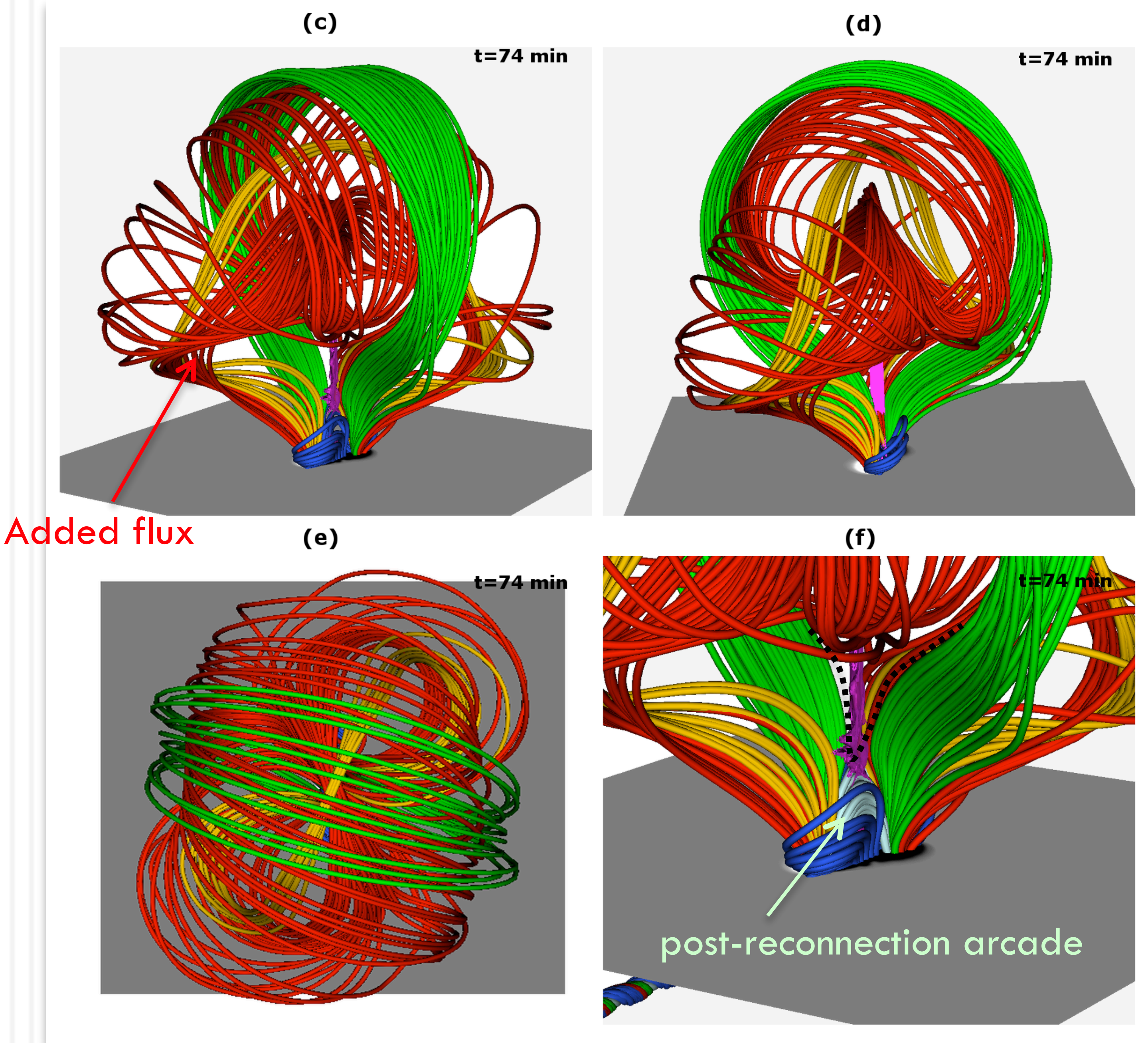
This process removes all the overlying tension resulting into an ejective eruption



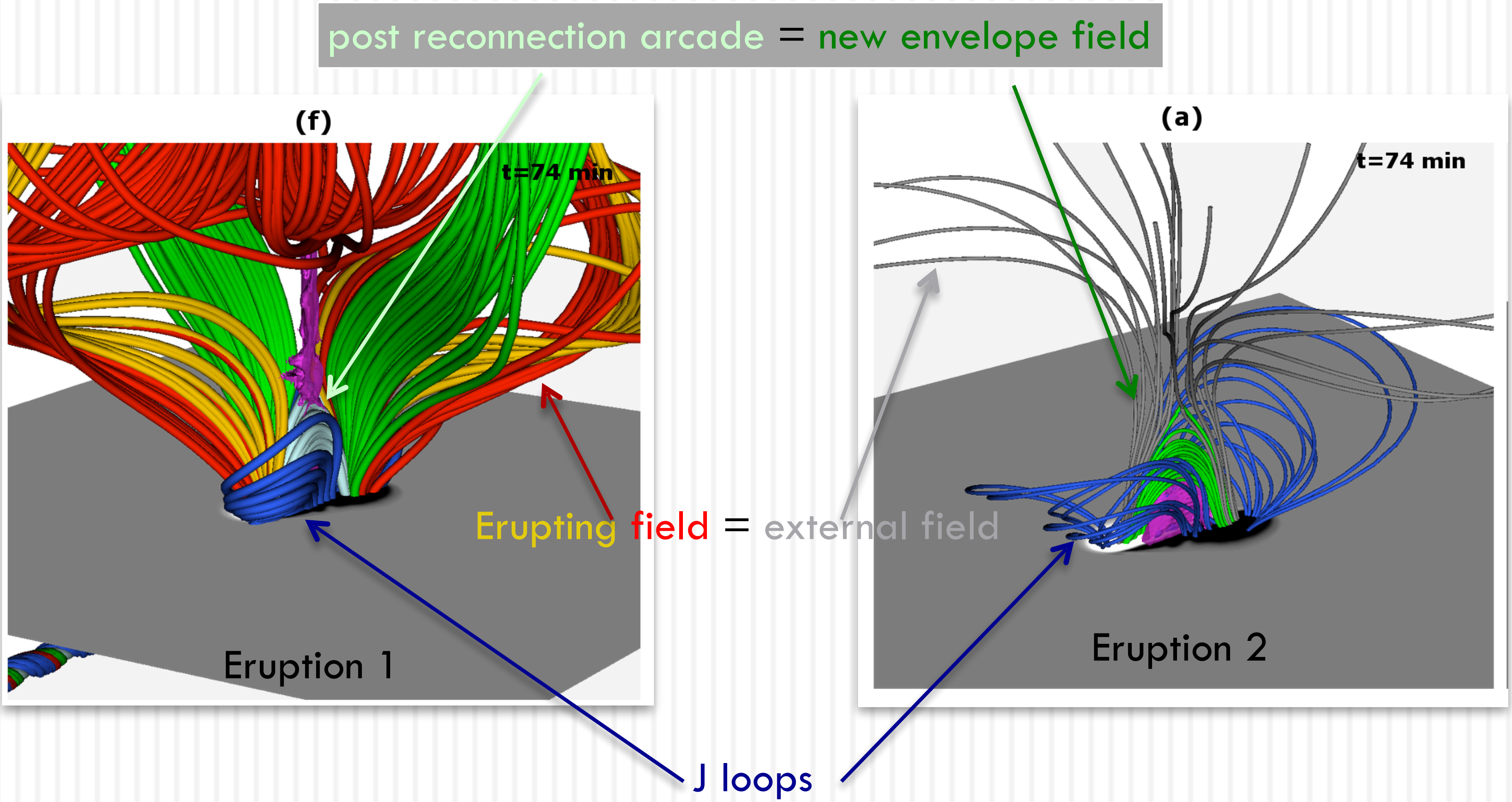



# 1st Eruption – Fieldlines

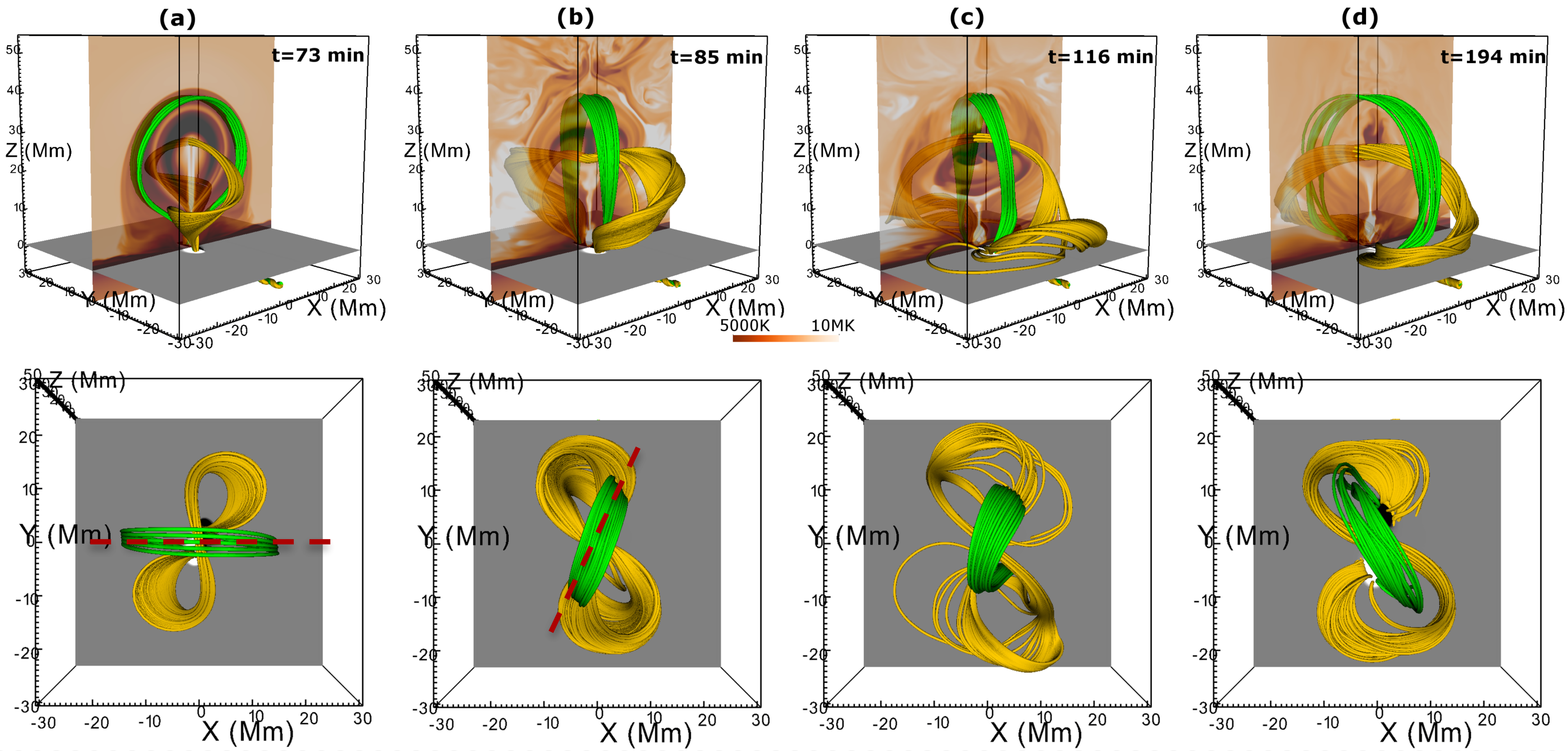


# 2nd Eruption – Mechanism I

1. The post-reconnection arcade forms the new envelope field
2. The previous eruption has created a magnetic external field



# 2nd Eruption – Mechanism II




Eruption 1

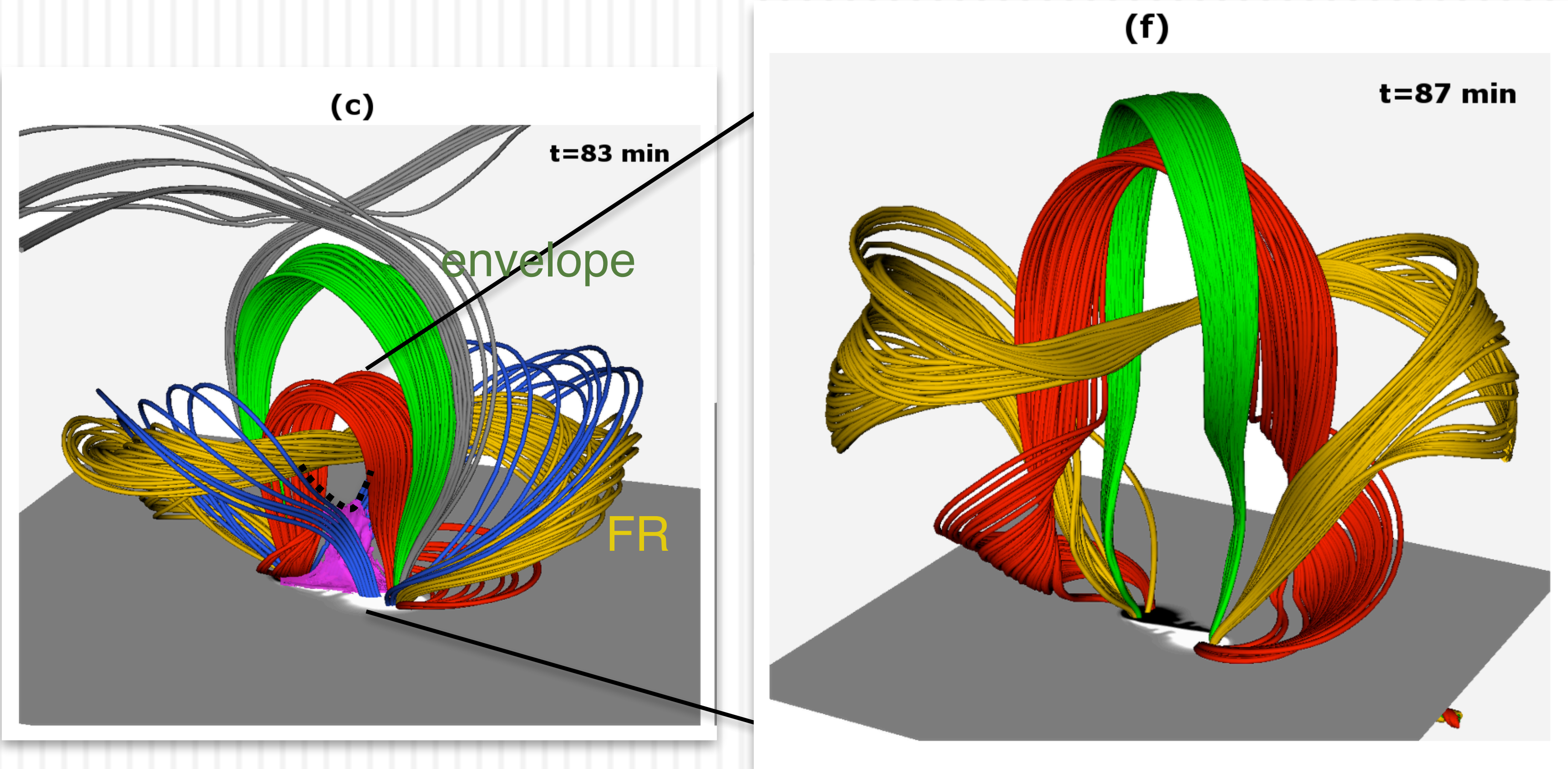
Eruption 2

Eruption 3

Eruption 4

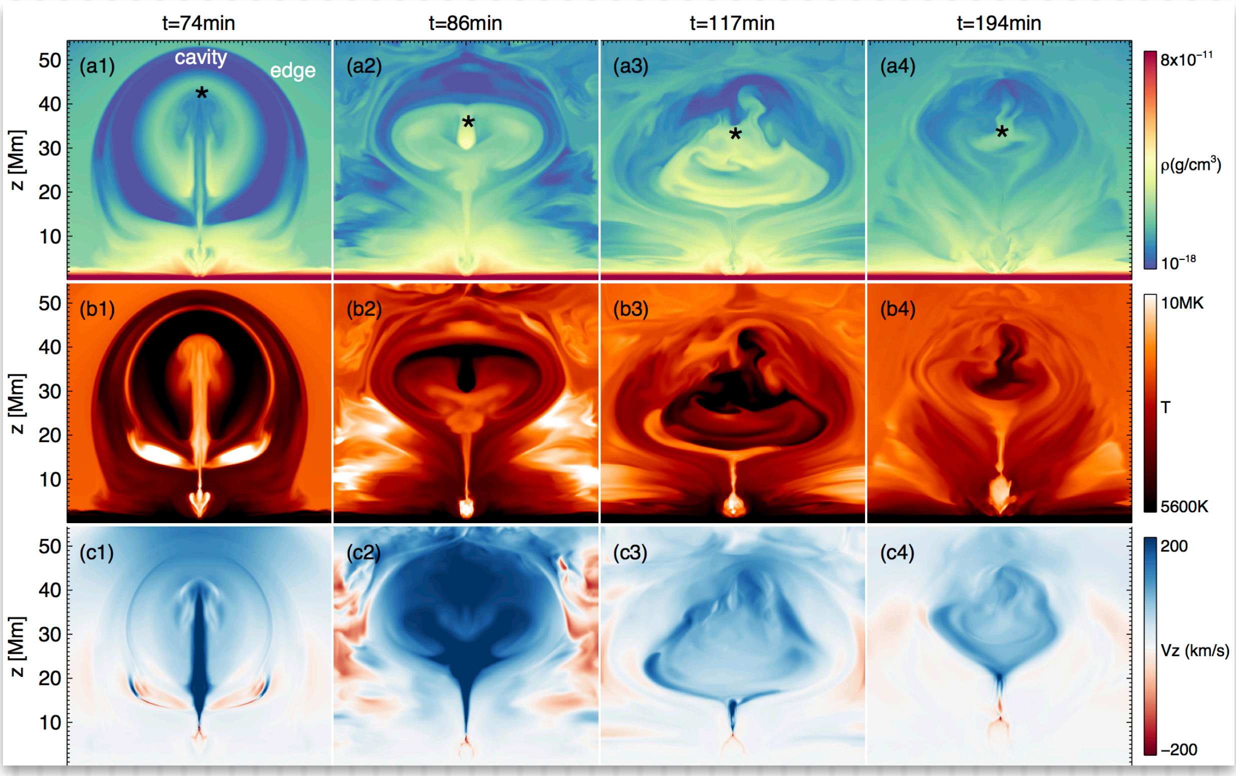
# 2nd Eruption – Mechanism III

1. Reconnection of Js form a FR (similar to 1st)
2. But the envelope fieldlines do not reconnect with themselves… Envelope field reconnects with the Js (Envelope – J tether cutting)
3. The reconnected lines twist around the flux rope becoming part of it



# Eruptions – Temperature/Density

Eruption 1 | Eruption 2 | Eruption 3 | Eruption 4



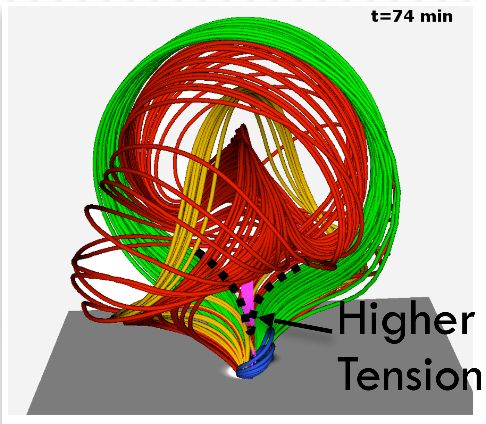

<u>Eruption 1</u>

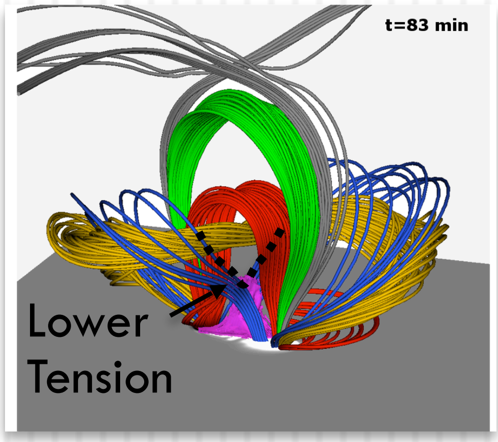
Hot plasma is injected into the central region through the jet (CME–like)

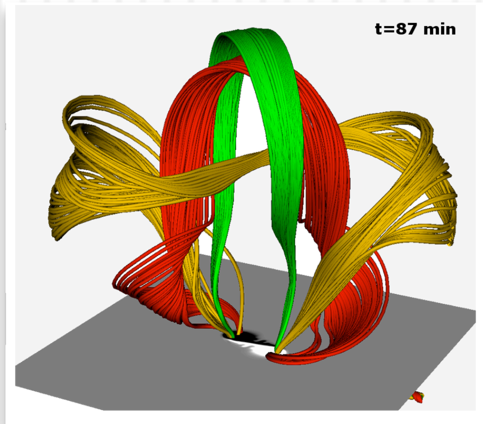
<u>Eruption 2,3,4</u>

Cold and dense plasma core. Hot plasma at the periphery

Dynamical heating of the CME core could be an indication for envelope-envelope tether cutting



# CME-like eruptions – Summary

**Main results:**

1. The flux ropes possibly become torus unstable and it undergoes full ejection due to tether-cutting reconnection.
2. The envelope field can reconnect with the J-loops and act as a tension removal mechanism
3. Hot plasma transfer in the central region differs with the location of the tether-cutting
4. Dynamical heating of the flux rope core is indication of the “typical” tether cutting

Syntelis, P; Archontis, V.; Tsinganos, K. Part I, 2017, ApJ
Syntelis, P; Archontis, V.; Tsinganos, K. Part II, 2017, Submitted